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NAVIGATED PIN PLACEMENT FOR ORTHOPAEDIC PROCEDURES

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NAVIGATED PIN PLACEMENT FOR ORTHOPAEDIC PROCEDURES

BACKGROUND OF THE INVENTION

The present invention relates to systems and methods for accurate positioning of tools, fasteners and implants within a patient. More particularly, the invention relates to orthopaedic surgical procedures requiring accurate shaping of the bone or placement of bone engaging elements.

Damage or disease can deteriorate the bones, articular cartilage and ligaments of human joints, such as the knee, which can ultimately affect the ability of the natural joint to function properly. To address these conditions, prosthetic joints have been developed that are mounted to prepared ends of the bones of the joint, namely the tibia and femur in the case of a knee prosthesis.

The implant components define interior mounting surfaces that often require involved cuts into the bone, such as the distal end of the femur or the proximal end of the tibia. The implant components are selected to restore or emulate as much of the natural motion of the knee joint as possible. Consequently, implant positioning with respect to the natural bone is critical. For instance, a proper implant will maintain the proper tension in the retained ligaments supporting the joint.

Preparation of the natural joint to receive a prosthesis must be painstaking to ensure the properly selected implant will work for its intended purpose. For instance, in preparing a knee joint to receive a prosthesis, the orthopaedic surgeon typically uses templates to determine the proper size of the implant components. The surgeon may also measure the joint gap and choose a spacer that can be used in the procedure to maintain that gap. Since the femoral component of the knee prosthesis requires complex cuts in the femur, a femoral resection guide is used, such as the resection guide **10** shown in **FIG. 1**. A saw guide **12** is aligned with the end of the femur **F** with its guide slot **14** oriented to

make the proper cut in the bone. The saw guide is supported on the bone by a mounting block **16** that is fastened to the distal end of the femur **F** by a pair of mounting pins **17**. The orientation of the saw guide **12** is adjusted by controlling an adjustment knob **19** and sliding an adjustment rod **18**.

While the vertical position of the saw guide slot **14** is adjusted by sliding the adjustment rod **18** relative to the mounting block **16**, the angular orientation of the saw guide is determined by the placement of the mounting pins **17** supporting the mounting block. It can be appreciated, then, that the placement of the mounting pins **17** must be as accurate as possible to ensure a proper cut. In order to account for the potential for error in initial placement of the pins, more complex cutting guide assemblies have been developed. These complex devices include multiple degree-of-freedom fine tuning adjustments that can be "dialed in" to optimize the orientation of the saw guide. While accurate bone cuts can be made with these complex devices, they are naturally more expensive and require greater maintenance than cutting blocks as simple as or more simple than the assembly **10** of **FIG. 1**.

Many orthopaedic procedures require performing operations on only partially exposed bones and joints. The use of an imaging modality such as intraoperative x-rays or CT scans can open the surgeon's "field of vision" without requiring greater tissue exposure of the patient. Image guided surgical techniques have been used in orthopaedic surgeries, as well as many other types of surgeries where the surgical site is difficult to view directly.

An example of an image guided surgery (IGS) system is shown in **FIG. 2**. An x-ray imaging apparatus **27** is situated adjacent the operating table **25** to provide an intraoperative view of the surgical site, in this case the femur **F**. An x-ray monitoring apparatus **28** provides means for viewing the x-ray scan as the femur is being prepared to receive an implant, for instance. The IGS system also includes a localizer apparatus **29** that provides means for determining the position of elements in the surgical arena. The apparatus **29** includes a

localizing device or sensor **31** that feeds information to a processor or computer **33** for display on a monitor **35**. The localizing device **31** can take on a variety of forms, but all geared toward receiving signals from an emitter or position tracking element associated with a part of the patient, such as femur, or a surgical component, such as a drill guide **38**. For instance, the localizing device **31** can constitute part of a visible light, IR, electromagnetic or RF triangulation system capable of fixing a position in space. Triangulation data from the localizing device **31** is fed to software within the processor that can calculate position information and generate a visual image on the display **35**. Further details of suitable IGS systems can be found in U.S. Patent No. 6,697,664, the disclosure of which is incorporated herein by reference.

As the disclosure of the **'664** Patent reveals, the typical image guided surgery system is complex and requires a great deal of equipment to provide real-time simulation and graphic display of the surgical site. What is needed is a system that allows for accurate bone resection or placement of surgical components without the expense and complexity of prior IGS systems.

SUMMARY OF THE INVENTION

In order to address this need, the present invention focuses on accurate placement of pins or screws into an object bone. The pins can then be used to position a standard cutting guide with the confidence that the bone resection conducted using the guide will be optimum. In order to accomplish this accurate pin placement, the present invention utilizes image guides surgical techniques, and particularly the use of a localizing sensor and position tracking elements associated with a surgical tool. In one embodiment of the invention, the surgical tool is a powered tool for placing a locating or support pin into a bone. The tool is outfitted with a position tracking element that can be sensed by the localizing sensor to determine the position of the tool in three-dimensional space. Similarly, the bone itself is provided with a position tracking element, at least initially, that will establish the spatial position of the bone.

A processor is linked to the localizing device or sensor to receive the data generated by the sensor. Software within the processor allows use selection of the proper location and attitude of the pin placement relative to the position tracking element associated with the bone. This position can be established using a pointer or other alignment device that is also provided with a position tracking device. The processor software can then calculate a relative difference between the spatial position of the bone and the spatial position of the proper pin location. Alternatively, if the bone is rigidly held so that it cannot move during the procedure, then only the spatial position of the pointer need be established.

Once the proper spatial location for the pin placement is determined, the surgeon manipulates the tool and its position data is sensed by the localizing device. The localizing device feeds this position information in real-time to the processor which compares the tool position to the proper location for the pin placement. In one embodiment of the invention, an annunciator provides a sensible signal to the surgeon to at least identify when the alignment of the tool matches the proper pin placement spatial position. The annunciator can provide

an audible signal indicative of the relative spatial position. For instance, the audible signal can be generated only when the tool and pin placement spatial data coincide. Alternatively, the software can calculate a "closeness" value indicative of how close the tool is to its proper position, and then the audible annunciator can modulate the audible signal in relation to that "closeness" value.

In another embodiment, the annunciator is a visual indicator. The visual indicator can range from a light that illuminates when the spatial positions coincide to a series of lights that signal "closeness" and coincidence. The visual indicator can also constitute an image on a display associated with the processor that signifies the position of the tool relative to the proper pin placement position.

In a further embodiment of the invention, the tool itself is linked to the processor. The tool can be controlled automatically by the processor in relation to the spatial information evaluated by the processor software. In a specific embodiment, the tool is automatically activated when its spatial position coincides with the proper pin placement position. Where the tool is a pin driving tool, the tool is activated to drive the pin into the bone. Where the tool is a drill for driving a screw into the bone, the drill can be activated when it is properly positioned. As a further alternative, the drill can be constantly running but is configured to prevent the drill bit from engaging the bone unless and until the tool is properly positioned. In a specific embodiment, the drill is outfitted with a sheath that covers the rotating drill bit as the tool traverses the surface of the bone. Once the drill reaches its correct location, the sheath retracts, allowing the drill to be advanced into the bone.

In another aspect of the invention, a guide apparatus is provided that facilitates accurate placement of a guide or support pin into a bone. In one embodiment, the guide apparatus comprises a mounting body that is fastened to the bone in the proximity of a pre-determined guide pin location. A guide arm supports a position adjustment assembly over the guide pin location. The position adjustment assembly permits gross and fine adjustments of a pin guide.

In this preferred embodiment of the invention, the pin guide is provided with a position tracking element that works through a localizing device or sensor to interactively evaluate the spatial position of the pin guide relative to the pre-determined guide pin location. Once the pin guide has been manipulated into coincidence with the pre-determined position, the surgeon can use the guide to drive a support pin into the bone.

Once the first pin has been properly position within the bone, a second pin can be introduced using the same guide apparatus. Alternatively, a cutting block can be mounted over the single support pin and then rotated into its proper alignment. The cutting block in this alternative embodiment is provided with its own position tracking element so that its spatial orientation can be evaluated in real-time. When the cutting block has been rotated into position, the cutting block itself is used as a pin guide for driving the second support pin into the bone.

It is one object of the present invention to provide systems and methods to facilitate making accurate cuts or resections of bone at a surgical site. It is a further object of the invention to utilize known image guide surgical techniques, while avoiding the high cost and complexity of such systems.

One benefit of the present invention is that it allows an orthopaedic surgeon to use conventional cutting blocks to perform bone resection procedures. Another benefit of the invention is that it can be used for a variety of functions in the orthopaedic arena, ranging from placing support pins for resection cutting blocks to accurate positioning of bone screws or pins. Other objects and benefits of the invention will become apparent upon consideration of the following written description taken together with the accompanying figures

DESCRIPTION OF THE FIGURES

FIG. 1 is a side view of an adjustable cutting block mounted to the distal end of a femur.

FIG. 2 is a perspective view of an operating room utilizing imaging equipment for image guide surgery.

FIG. 3 is a perspective view of a system for accurate pin placement in a femur, in accordance with one embodiment of the present invention.

FIG. 4 is a flowchart of software steps performed by a processor in accordance with the present invention.

FIG. 5 is a side view of a driving tool in accordance with one aspect of the present invention.

FIG. 6 is a side view of an alternative driving tool for use with the present invention.

FIG. 7 is a perspective view of a system for placing a pin through an opening in a femoral nail using the present invention.

FIG. 8 is a perspective view of a guide apparatus in accordance with a further embodiment of the invention for positioning a pin in a bone.

FIGS. 9(a)-(c) are representations of sequential steps for positioning a cutting block using the present invention.

FIG. 10 is an enlarged exploded perspective view of the guide apparatus shown in **FIG. 8**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and described in the following written specification. It is understood that no limitation to the scope of the invention is thereby intended. It is further understood that the present invention includes any alterations and modifications to the illustrated embodiments and includes further applications of the principles of the invention as would normally occur to one skilled in the art to which this invention pertains.

The present invention provides systems and methods that utilize image guided surgical techniques and systems. More particularly, the invention utilizes a localizing device, such as the localizing sensor **31** shown in **FIG. 2**, and position tracking elements, such as the element **42**, that cooperate with the localizing device to establish the spatial position of a component. A processor, like the processor **33** in **FIG. 2**, receives data from the localizing device and calculates the "global" or spatial position of the component. The invention can be implemented with a variety of localizing devices, position tracking elements and software used to determine spatial positions, including known devices and systems such as those described in U.S. patent No. 6,697,664 described above. The nature of the localizing device and tracking elements depends upon the type of signal being transmitted, which in turn may be governed by cost, line of sight limitations and the potential for interference with other equipment used in the operating room. For the purposes of the following description, it is contemplated that the position tracking elements emit an infrared (IR) signal and the localizing device includes an array of IR receivers.

One embodiment of the present invention is depicted in **FIGS. 3** and **4**. In this illustration, the goal is to position a bone engaging element or support pin at a particular location **X** in a bone, such as a femur **F**. In a first step of the procedure, as reflected in the flowchart of **FIG. 4**, the pin location **X** is spatially

located relative to a localizing device **31**. A position tracking element **45** can be associated with the femur **F** and the pin location **X** calibrated to the location of the tracking element on the bone. Alternatively, a locating pin carrying its own position tracking element can be used to locate the pin location **X** on the femur **F** and transmit that location data to the localizing device **31**. Once the location data has been transmitted, the locating pin is removed. Using the former approach, the location **X** can be established even when the bone moves slightly. Using the latter approach relies upon holding the femur in position by restraining the bone against movement so that the stored information regarding the position **X** is not obsoleted. With either approach, a position processor **49** can determine spatial coordinates of the pin location **X** using known algorithms. The nature of the spatial coordinate calculation and the form of the coordinates are not critical provided the same type of data and calculations are performed for all position tracking elements.

Once the pre-determined pin location has been established, the surgeon can manipulate a driving tool **40** in the vicinity of the pin location **X**. In one feature of the invention, the driving tool includes a position tracking element **47** that transmits to the localizing device **31**, as shown in **FIG. 3**. Thus, the spatial position of the tool **40** can be established in real-time. Preferably, the position tracking element **47** includes enough IR transmitters so that not only the spatial position but also the orientation of the tool can be determined. In other words, the object is to ascertain where the working end **41** of the tool is located relative to the femur **F** and to determine the alignment of the working end, since this alignment will determine whether the bone engaging element or pin is inserted at a proper angular orientation relative to the bone.

Returning to the flowchart in **FIG. 4**, once the pre-determined pin location has been established, software within the processor **49** evaluates the current position of the tool **40** using known techniques, and compares that current position to the spatial position of the pin location **X**. If the spatial coordinates of the tool do not match the spatial coordinates of the pin location **X**, the processor

continues to receive position data. The degree of coincidence required to establish a spatial match can be pre-determined or calibrated to the size of pin and the criticality of the pin placement. For instance, an acceptable pin placement may be within a radius of about 1 mm and about 1 degree of the pre-determined pin location **X** without adversely affecting the ensuing orthopaedic procedure. Again, the processor can use known proximity tests to determine spatial coincidence or not.

Once these coordinates coincide, the processor activates an annunciator **50** (**FIG**. **3**) that provides a sensible indication that the tool **40** is properly positioned. In one embodiment, the annunciator provides an audible signal, such as a beep, to indicate that the driving tool **40** is positioned over the location **X**. In a modification of this embodiment, the processor can be programmed to variably activate the audible annunciator. For instance, the annunciator **50** can emit a sound of one frequency as the tool is manipulated in search of the proper location, and then emit a sound of a different frequency and/or intensity when spatial coincidence is achieved. The modulation of the sound can be calibrated to the proximity of the working end **41** of the tool to the location **X**.

Once the annunciator signals spatial coincidence between the working end **41** and the location **X**, the tool **40** can be activated to place the fastener or pin into the femur **F**. Where the annunciator is sensed by the surgeon, the surgeon can operate the tool in a known manner. In an alternative, described in more detail herein, the processor **49** can direct the activation of the driving tool.

In certain embodiments of the invention, the annunciator provides a visual indication of spatial coincidence. In a specific embodiment, that visual indication can be projected on a display device, such as the monitor **35** of **FIG**. **2**. This option is less desirable because it requires the surgeon to watch a monitor rather than the surgical site (at least in the absence of a heads-up display on a surgical visor). More desirably, the annunciator **50** can include one or more lights placed in a position that can be sensed by the surgeon without removing his/her

concentration from the patient at hand. Like the audible annunciator described above, the visual annunciator can be activated only when spatial coincidence is achieved. Alternatively, the visual annunciator can modulate the light, such as by strobing the light, varying the color or sequentially activating an array of lights indicative of proximity to the location **X** and eventually spatial coincidence.

In another embodiment of the invention, a pin driving tool **55** is configured to propel a pin **56** into bone. The tool can be a driving tool known for use in the orthopaedic field. The tool can be spring-loaded, electromagnetic, pneumatic or a combustion-type tool. The tool **55** includes a position tracking element **58**, as described above to provide real-time data regarding the position and orientation of the tool relative to a pin implantation site on a bone. The tool **55** includes an on-board controller **67** that is connected via a communication link **62** to a master controller **60**. The master controller **60** can be part of the processor **49** and operates to send signals to the on-board controller **67**. The communication link **62** can be a wire connecting the two components or can be wireless, such as an RF transmission.

In one aspect of this embodiment, the annunciator **64** is associated with or mounted on the tool **55** in a position where it is readily visible to the surgeon. The tool **55** can include a plurality of LEDs **65a**, **65b** that are used to indicate closeness to and coincidence with the pin location. The annunciator is connected to the on-board controller **67** that responds to signals from the master controller **60** to activate the appropriate LED **65a**, **65b**. In a specific embodiment, one LED **65a** can be activated as the surgeon searches for the proper pin location, while the other LED **65b** can be activated once the pin **56** is situated over the pre-determined pin location.

In another embodiment of the present invention, the system contemplates automatically controlling the operation of the driving tool when its position coincides with the pre-determined pin position. The on-board controller **67** can also be connected to the motor **68** to activate the motor in response to a signal

from the master controller **62**. With this embodiment, the surgeon need not activate the tool in response to an annunciator signal. Automatic control thus facilitates the pin placement process.

This automatic control feature can also be implemented where the tool is a drill operable to prepare a bore in bone to receive a bone screw, for instance. Thus, as shown in **FIG. 6**, a drill **70** can include a tracking element **74** and an on-board controller **78**. The on-board controller **78** communicates with the processor **49** and master controller **60** through a communication link **76**. These components can be configured similar to the like components discussed above with respect to **FIG. 5**. Similarly, the on-board controller **78** can be connected to the motor **72** of the drill **70** to activate the drill at the appropriate time.

In a further alternative, it is contemplated that the drill **70** will be continuously running as the surgeon searches for the proper location to drill into the bone. In this instance, the present invention provides a mechanism for preventing access to the bone until spatial coincidence is achieved. In one specific embodiment, a sheath **80** is provided that encloses or covers the drill bit **71** as it is rotating. The sheath is connected to a retraction mechanism **82** that retracts or extends the sheath in response to a signal from the on-board controller **78**. The retraction mechanism **82** can take on a variety of forms, such as the rack and pinion configuration depicted in **FIG. 6**. The mechanism **82** is preferably electrically operated and capable of rapid retraction of the sheath **80**.

The drill **70** includes its own power switch **73** to provide the surgeon with absolute control over the activation of the drill. Thus, rather than rotating the drill bit **71** continuously during the procedure, the surgeon can elect to de-activate the drill until the bit is nearly aligned with the proper location. When the switch **73** is turned on, the on-board controller then takes charge of activating the motor **72** and/or retracting the sheath **80**.

In an alternative approach, the bit **71** itself can be retracted into the body of the tool **70**. With this approach, the retraction mechanism **82** can be engaged

to the drill motor **72** and operate to move the motor back into the body of the tool with the bit **71** engaged thereto. In yet another alternative, the cutting edges of the drill bit **71** can be configured to be withdrawn as the bit is rotating, and then extended when a drilling operation is to be performed.

With the approaches of **FIGS**. **3-6**, the invention provided means for gauging the spatial position of the working tool, such as the pin gun **55** or drill **70**. These embodiments utilize annunciators to signify alignment of the working end of the tool with the pre-determined location on the bone. In certain variations, an on-board controller automatically controls the operation of the tool in response to an indication of spatial alignment.

These same aspects of the present invention can be used to drill into a bone at a predetermined position. For instance, as shown in **FIG. 7**, an intramedullary nail **88**, disposed within the medullary canal of a bone **F**, includes an opening **90** therethrough. In certain orthopaedic procedures, it is necessary to extend a fastener or bone engaging element through the opening **90** *in situ*. In this instance, a position tracking element **89** can be associated with the intramedullary nail **88**, the bone **F** or the opening **90** itself. The processor **49** evaluates the data transmitted by the tracking element **89** to determine the position of the opening **90**. The working tool **85**, which is typically a drill, is also provided with a position tracking element **86**. The real-time position of the drill **85** is assessed by the processor as described above. When the spatial position of the working end of the drill coincides with the pre-determined position of the opening **90**, any one of the protocols described above can be implemented – i.e., an annunciator can be activated to prompt the surgeon to operate the drill at that location, or the drill can be automatically controlled.

In a further approach of the present invention, a pin guide, rather than the pin itself, is navigated into position using the image guides surgical techniques described above. In this embodiment, a guide apparatus **10** includes a body **101** mounted to a bone **F** by mounting pins **103**, as shown in **FIG. 8**. The location of

the mounting body is not critical, but is preferably near the pre-determined location **X** for the placement of a pin used to support a standard cutting block (such as the cutting block **C** shown in **FIG. 9(b)**). The guide apparatus includes a guide arm **105** supported by the block **101** and configured to extend across the bone **F** toward the pin location **X**. The guide arm can be pivotably mounted within a bore **104** defined in the mounting block **101** or can be rigidly fixed to the block. If the guide arm **105** is pivotably mounted, it is preferably mounted within a bushing that adds frictional resistance to pivoting of the guide arm to prevent unnecessary movement of the arm. The pivot mount can also include a clamp to fix the guide arm **105** to the mounting block **101** when the arm has been pivoted to its preferred position.

The guide arm **105** supports a position adjustment assembly **110** that is configured to align a pin guide **107** with the pre-determined location **X**. The pin guide **107** is outfitted with a tracking element **108**, which can be similar to the tracking elements discussed above. The tracking element is used in conjunction with a localizing device, such as the device **31** described above, for a real-time determination of the spatial location of the pin guide **107** relative to the pin location **X**, the spatial coordinates of which have been determined beforehand. The relative position between these two points is calculated in the manner described above to determine whether the pin guide spatially coincides with the pin location. In the prior embodiments, the working tool was manually manipulated by the surgeon as the position of the tool was sensed in real-time. With the embodiment of **FIG. 8**, the "working tool" is the pin guide and its position is controlled indirectly by manipulation of the position adjustment assembly **110**.

With this embodiment, the ultimate goal is to accurately position a standard cutting guide, such as the guide **C** shown in **FIG. 9(b)**, relative to a bone, such as the femur. The guide apparatus **100** is manipulated until the pin guide **107** coincides with the pre-determined pin location **X** (**FIGS. 8** and **9(a)**). When the pin guide is properly aligned, the surgeon can use the guide to drive a support pin P_1 into the bone. In one approach, the guide apparatus is used to

place a second support pin **P_2** as shown in **FIG. 9(c)**, and the cutting block **C** is mounted on the pins.

In an alternative approach, the first pin **P_1** is positioned using the guide apparatus **100**. The guide apparatus is then removed from the bone **F**. The cutting block **C** can be provided with a position tracking element **112** that sends signals to a localizing device in the manner described above. The position of the cutting block **C** can then be compared to a predetermined position value associated with either the cutting block or with the second support pin **P_2**. In the latter case, the cutting block **C** is acting as like the pin guide **107** in that it is being positioned to align with a second pin location **Y** (**FIG. 9(b)**) and is used to guide a pin driven into the bone **F** by the surgeon.

When the first pin **P1** is placed within the bone, the cutting block **C** is mounted on that pin, as shown in **FIG. 9(b)**. The cutting block is then rotated about the first pin until its position coincides with the proper position for the second pin **P_2**. This position is verified using information transmitted by the position tracking element **112**, read by the localizing device **31** and deciphered by the processor **49** (see **FIG. 3**). At that point, the second support pin **P_2** can be driven into the bone **F** using the cutting block as a pin guide.

It can be appreciated that this embodiment of the invention accommodates a simple standard cutting block. Since the location of the mounting pins **P_1** and **P_2** is accurately navigated, there is not need for the cutting block to include any gross or fine adjustment capabilities. Of course, differently sized cutting blocks may be required for differently sized bones. This size difference can be accounted for in establishing the pre-determined pin placement locations **X** and **Y**.

The details of one specific embodiment of the position adjustment assembly **110** are shown in **FIG. 10**. This assembly permits gross and fine adjustments to the position of the pin guide **107**. It is understood that this adjustment assembly can work in conjunction with the annunciators **50** or **64**

described above. In particular, an annunciator can signify coincidence between the position of the pin guide **107** and the pre-determined pin location(s) $\mathbf{P_1}$ (and $\mathbf{P_2}$). When the annunciator is activated, the surgeon stops making adjustments with the position adjustment assembly **110**.

In one embodiment of the invention, the position adjustment assembly **110** includes a gross positioning block **115** that is slidably mounted on the guide arm **105**, as shown in **FIG. 10**. The gross positioning block **115** can translate or rotate along the guide arm **105** in the degrees of freedom $\mathbf{D_1}$ and $\mathbf{D_2}$, as indicated by the directional arrows in **FIG. 10**. Preferably the block **115** includes a friction bushing (not shown) to increase the static and sliding friction between the block and the guide arm. The block **115** can also incorporate a clamp (not shown) for fixing the position of the block relative to the guide arm once a gross position of the block has been established.

The gross positioning block **115** supports a fine adjustment block **117** with a fine adjustment mechanism **118** disposed therebetween. The fine adjustment block **117** supports a support arm **126** at an angle relative to the guide arm **105**. Preferably, the support arm **126** is situated at a right angle to the guide arm, as depicted in **FIG. 10**. The support arm **126** is preferably fixed within the fine positioning block **115**.

The fine adjustment mechanism **118** is configured to permit small changes in the position of the fine positioning block **117** relative to the gross positioning block **115**. In other words, the fine adjustment mechanism **118** permits small adjustments in the spatial position of the pin guide **107** in the translational degree of freedom $\mathbf{D_1}$ (see also **FIG. 8**). The fine adjustment mechanism **118** can assume a variety of forms capable of producing minute changes in relative position, preferably on the order of 0.1 - 0.5 mm. In a specific embodiment, the mechanism **118** can include a thumbwheel gear **120** rotatably mounted within the gross positioning block **115** and a mating rack gear **122** mounted within the fine positioning block **117**. A dovetail mount **124** can be provided between the two

blocks **115**, **117** to slidably support the fine positioning block on the gross positioning block and maintain the two gears **120** and **122** in contact. The thumbwheel gear can be mounted within the block **115** so that a portion of the gear **120** is accessible to be manually rotated by the surgeon to make fine positional adjustments in the degree of freedom $\mathbf{D_1}$.

As explained above, a support arm **126** projects from the fine positioning block **117**. A second gross positioning block **115'** is slidably mounted on the support arm **126** in the same manner as the block mounted on the guide arm **105**. A second fine positioning block **117'** and a second fine adjustment mechanism **118'** can be provided to permit fine adjustments in the translational degree of freedom $\mathbf{D_3}$. The gross and fine positioning adjustment capabilities in the degrees of freedom $\mathbf{D_3}$ and $\mathbf{D_4}$ relative to the support arm **126** can be the same as the adjustments accomplished relative to the guide arm **105** described above.

The fine adjustment block **117'** supports a vertical support arm **128** to which the pin guide **107** is mounted. The vertical support arm can be slidably mounted within the block **117'** for translation in the degree of freedom $\mathbf{D_5}$ and rotation in the degree of freedom $\mathbf{D_6}$. Again, the mount between the block **117'** and the vertical support arm **128** can include a friction bushing to control the movement of the arm relative to the block. Alternatively, the vertical support arm **128** can include splines **129** at its free end. The fine positioning block **117'** can include a thumbwheel gear **131** that meshes with the splines **129** to permit fine rotational adjustments of the arm **128** in the degree of freedom $\mathbf{D_6}$. The splines **129** allow the arm **128** to translate vertically relative to the thumbwheel gear **131** without disturbing the fine rotational adjustment capability. Fine adjustment in the vertical translational degree of freedom $\mathbf{D_5}$ is typically not required because the pin guide **107** can be moved into direct contact with the bone **F** once the positional adjustments have been made in the other degrees of freedom. The fine rotational adjustment capability provided by the splines **129** and thumbwheel

gear **131** can be implemented in the gross positioning blocks **115** and **115'** to accommodate fine rotational adjustments in the degrees of freedom $\mathbf{D_2}$ and $\mathbf{D_4}$.

In using the guide apparatus **100** of the present embodiment, the gross position of the pin guide **107** can be established relative to bony landmarks on the bone **F**. The fine adjustment thumbwheel gears **120**, **120'** and **131** can be manipulated as the real-time spatial position of the pin guide **107** is reported using the position tracking element **108**. When the spatial position of the pin guide coincides with the pre-determined pin location(s) **X** (or **Y**), the pin guide can be moved into contact with the bone and the surgeon can drive a pin $\mathbf{P_1}$ (or $\mathbf{P_2}$) into the bone using a standard driving tool.

The systems and methods of the present invention are not limited to the pin placement or drilling operation s described above, or to any particular location in the body. For instance, the bone being prepared can be anywhere in the skeletal structure, such as the shoulder, elbow, hip, ankle, spine and cranium. The approach described in connection with **FIGS. 9(a)-(c)** can be used for guide placement of a bone plate, instead of the cutting guide shown the figures. For instance, in some orthopaedic procedures, a bone plate is fastened to a bone spanning a fracture. Accurate placement of the plate and associated bone fasteners can be facilitated with the present invention.

The invention is particularly suited for precision bone working operations. Thus, the invention is not limited to pin placement or drilling into bone, but can include other operations, such as cutting, burring, polishing, grinding, rasping, or other similar operations. For instance, in one alternative procedure, it is necessary to prepare the distal end of the femur to receive an femoral implant. This preparation can require shaving, burring and polishing the distal end of the femur using an appropriate tool. The tool would carry the position locating device **47** described above so that the working end of the tool can be established in real-time. The tool can be activated as described above when it aligns with an array of stored locations or falls within a range of pre-determined locations on the

bone. Thus, in the case of a burring tool, the surgeon can move the tool across the distal end of the femur while the tool spatial position is determined by the processor **49**. When the burring tool is at a location that has been previously determined to require finishing, the surgeon can be prompted to activate the tool by an annunciator **50**, or the tool can be automatically activated in the manners described above. Other tools can be similarly manipulated using the techniques and systems of the present invention.

While the invention has been illustrated and described in detail in the drawings and foregoing description, the same should be considered as illustrative and not restrictive in character. It is understood that only the preferred embodiments have been presented and that all changes, modifications and further applications that come within the spirit of the invention are desired to be protected.